



search for hidden sector ('dark') vector bosons, V_D , in $H \rightarrow Z V_D \rightarrow 4l$

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'hidden sector' or 'dark' vector particle study



- **particle physics motivation**
 - theoretical arguments (extra U(1)'s, hidden sector, etc)
 - dark matter candidates
 - muon g-2
- **motivation from astrophysics**
 - Pamela data showing electron excess in cosmic rays; no antiproton excess
 - Fermi/GLAST data; electron excess
 - AMS data; positron excess



selected recent references



- HS Lee, M. Sher, [arXiv:1303.6653](https://arxiv.org/abs/1303.6653) (2013)
- P. Langacker, Rev Mod Phys 81 1199 (2008)
- T. Han talk at Higgs Snowmass Workshop, Princeton Univ (2013)
[http://physics.princeton.edu/indico/contributionDisplay.py?
contribId=7&sessionId=0&confId=127](http://physics.princeton.edu/indico/contributionDisplay.py?contribId=7&sessionId=0&confId=127)
- W. Marciano talk at Dark Forces Workshop (2012)
[https://agenda.infn.it/getFile.py/access?
contribId=22&sessionId=11&resId=0&materialId=slides&confId=4
897](https://agenda.infn.it/getFile.py/access?contribId=22&sessionId=11&resId=0&materialId=slides&confId=4897)
- An, Huo, Wang, arXiv:1212.2221v1 (2012)
- Carone arXiv:1301.2027v1 (2013)
- . . . (plus others)



Higgs-like particle (HLP) ‘dark’ decays

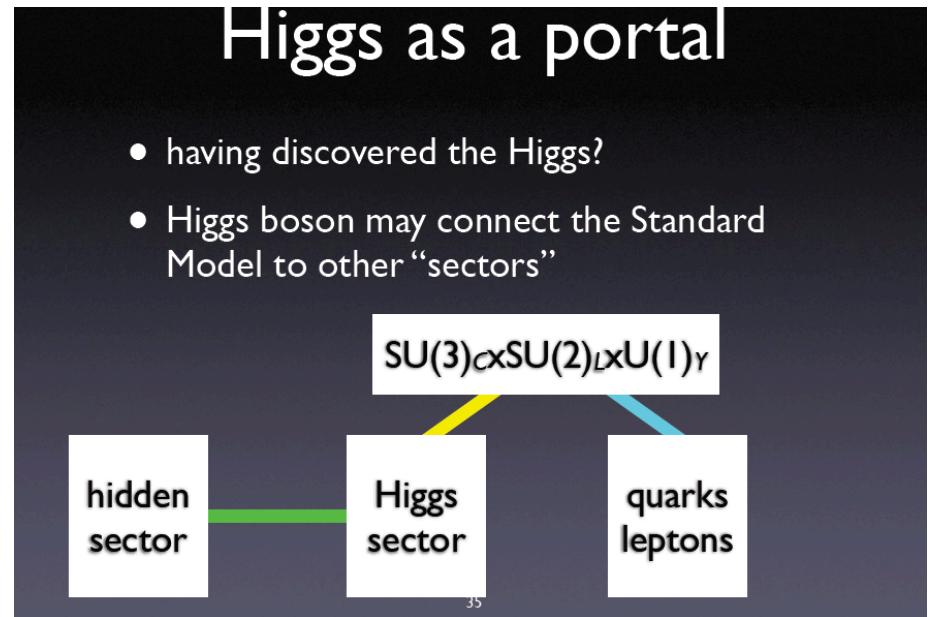


- $H \rightarrow \gamma + V_D$
- $H \rightarrow V_D + V_D$
- $H \rightarrow Z + V_D$

$$-V_D \rightarrow e^+e^- , \mu^+\mu^-$$

- hidden sector photon (γ') or hidden sector Z^0 -boson (Z'); also called dark photon (γ_D) or Z^0 -dark (Z_D); generically labeled V' or V_D

today

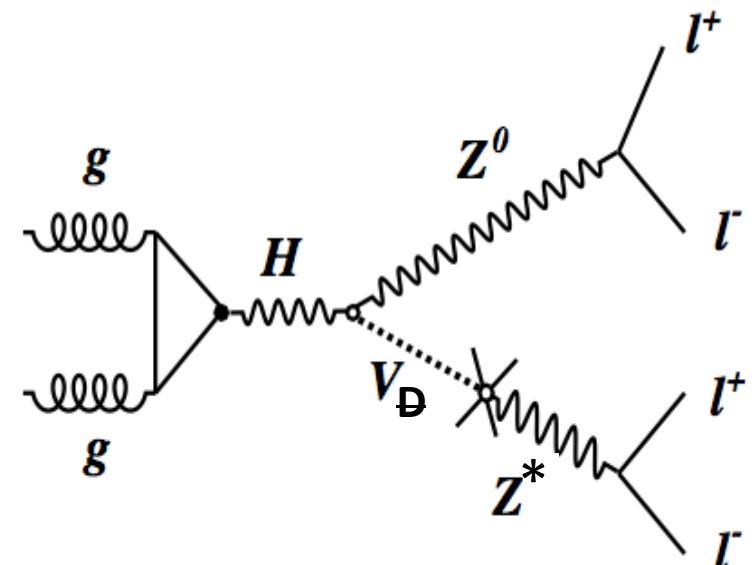
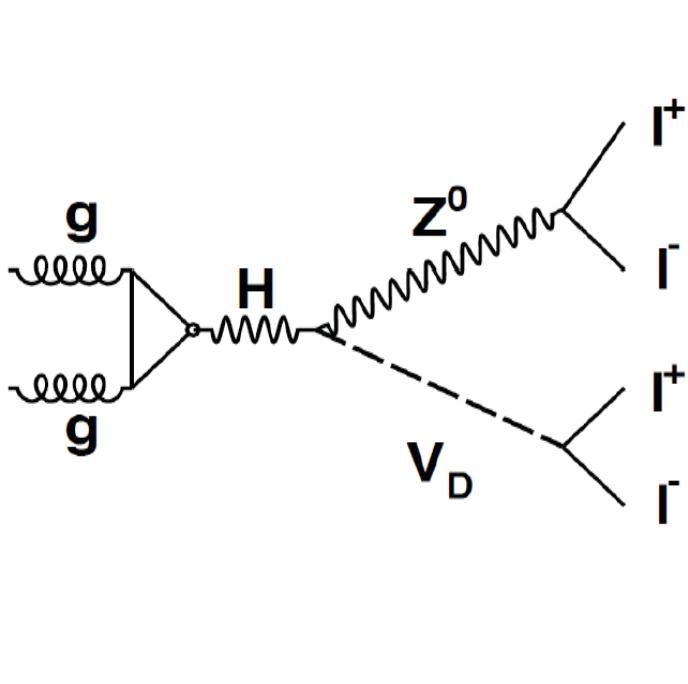




initial process to study:

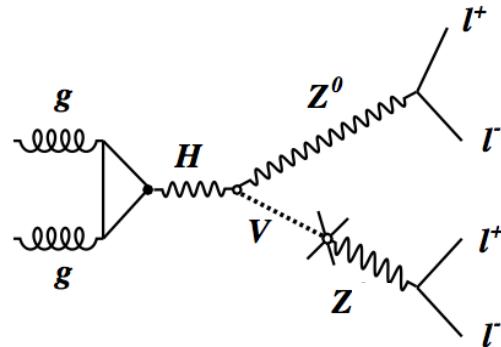


- Higgs produced via gg fusion
- Higgs decays to hidden sector (“Dark”) V-boson and to Z-boson
- four leptons in final state
- presence of V_D may or may not give displaced vertex (mixing)
- V_D is a vector boson (Z' , Z_D , γ' , γ_D)

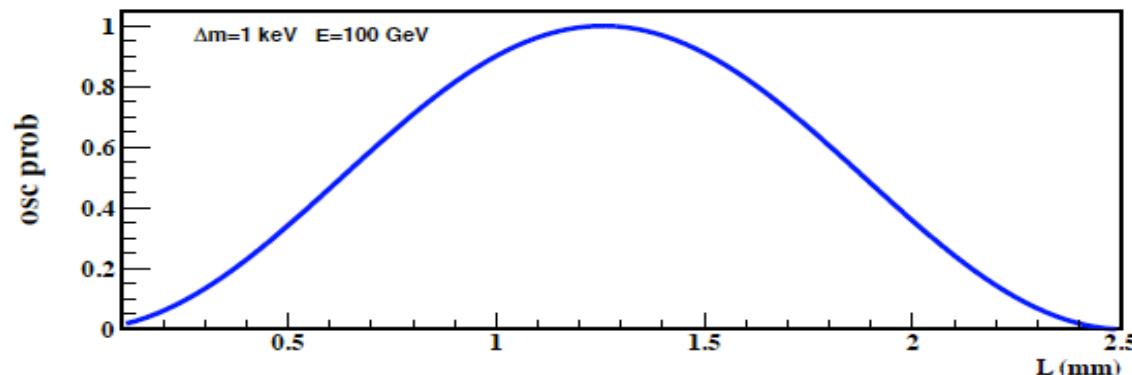
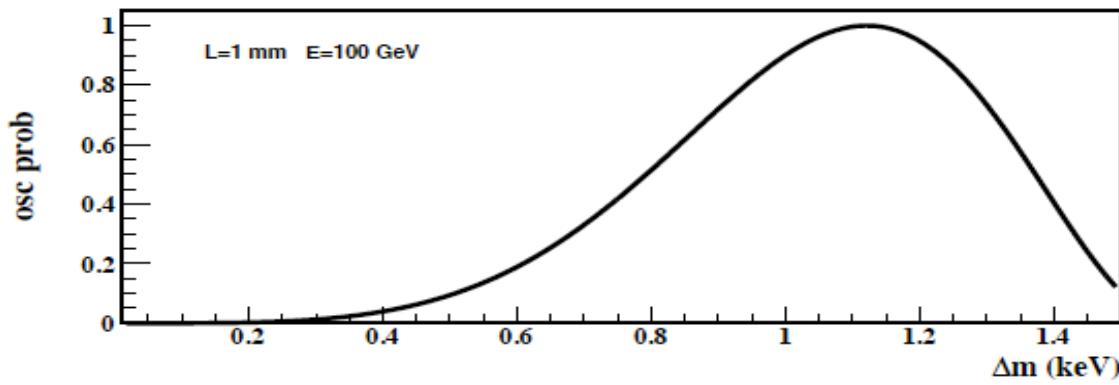




kinetic mixing



$$P_{osc} = 4 \chi^2 \sin^2 \left(\frac{|m_Z - m_{V_D}|^2 L}{4E} \right)$$



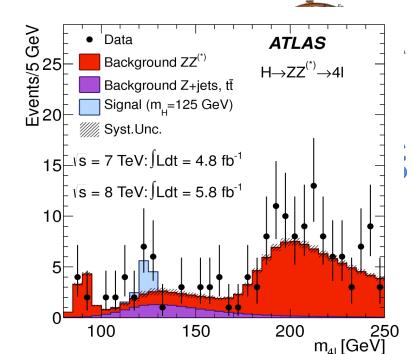
mixing probability
maximum for masses
approximately equal
and baseline (L) within
vertex cut limit

$\chi < 0.1 - 0.01$

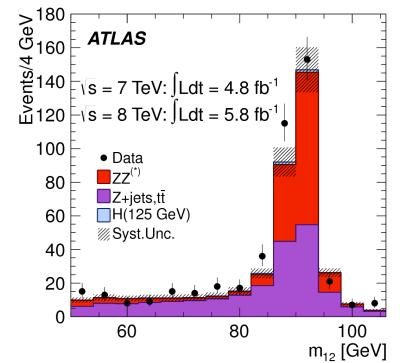


strategy

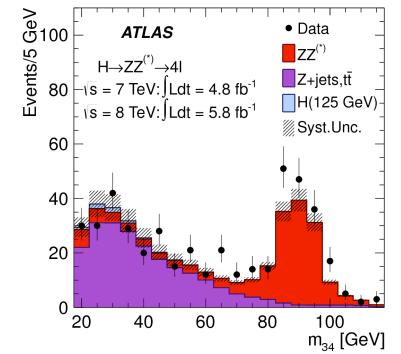
- 1. use events from HLP decays: $H \rightarrow ZZ^* \rightarrow 4l$
 - 38 HLP decays to 4e, 4 μ , 2e2 μ using MVA (BDT)



- 2. use Z and Z^* mass distributions
 - leading dileptons: invariant mass closest to Z^0 PDG value
 - subleading dileptons: highest invariant mass
- 3. search for narrow peak or excess above background in Z^* mass distribution; signals V_D
 - use RooStats and BumpHunter tools



on shell $Z \rightarrow 2l$



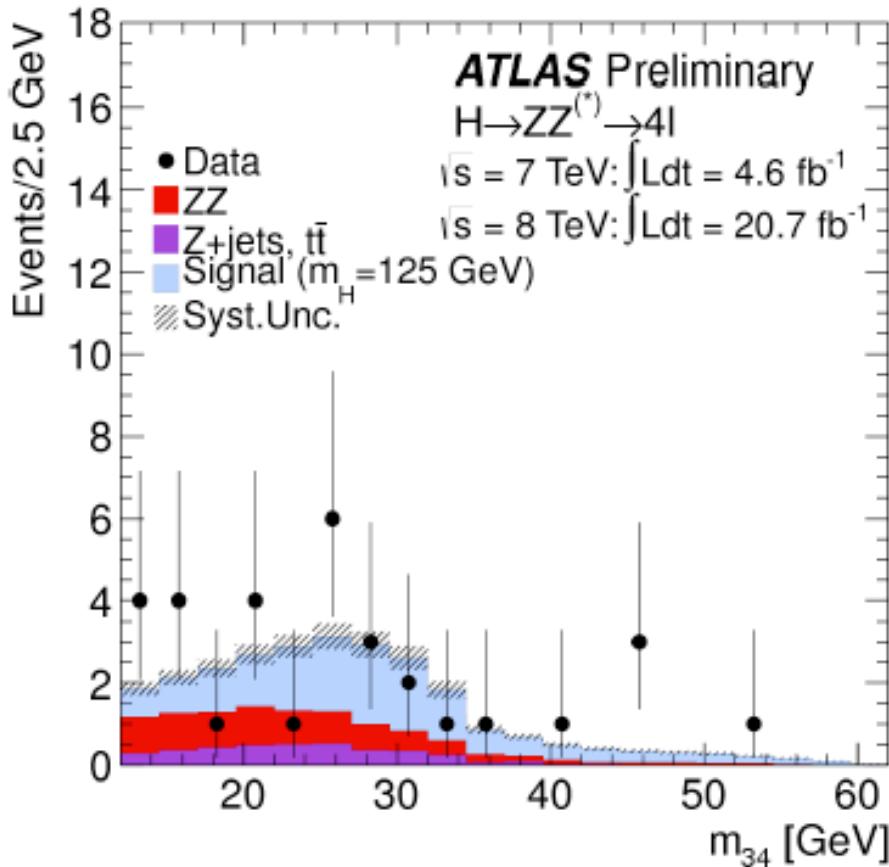
off shell $Z^* \rightarrow 2l$



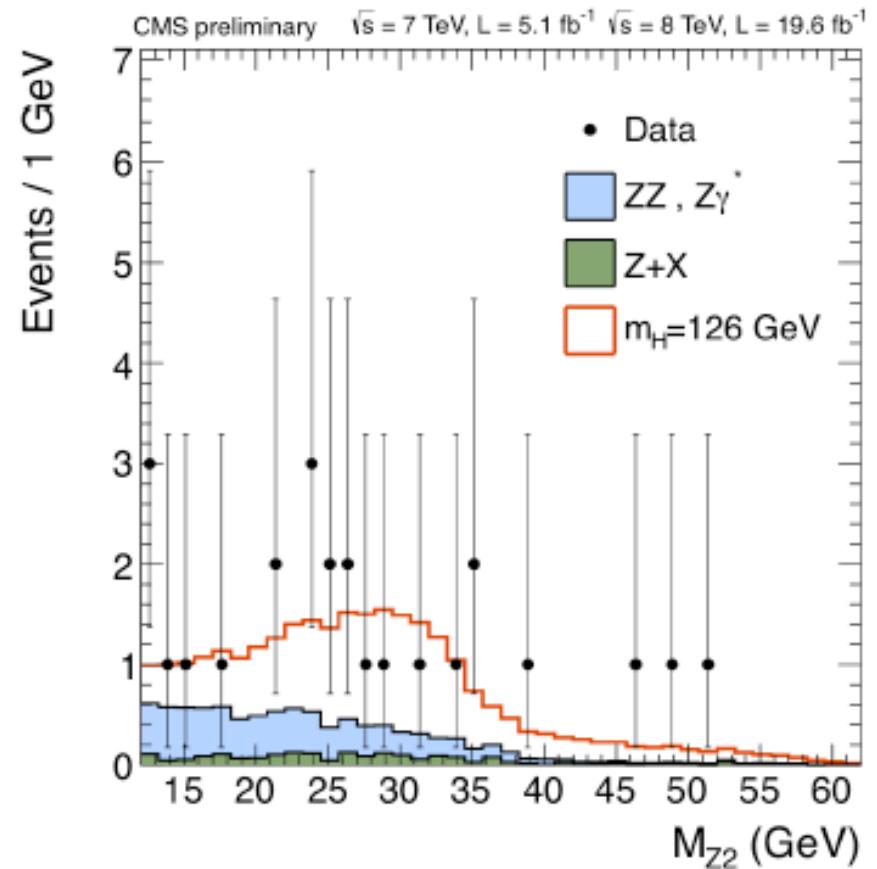
sub-leading lepton pair: ATLAS and CMS



120-130 GeV



121.5-130.5 GeV



Christos Anastopoulos (CERN) Higgs meeting 19-Mar-2013
<https://indico.cern.ch/conferenceDisplay.py?confId=241970>



strategy



- for an integrated luminosity of 20.5 fb^{-1} at 8 TeV, we get 38 HLP decay events to four leptons, using multivariate analysis;
- determine branching fraction $H \rightarrow ZV_D \rightarrow 4l$ relative to branching fraction $H \rightarrow ZZ^* \rightarrow 4l$

$$\frac{bf(H \rightarrow ZV_D \rightarrow 4l)}{bf(H \rightarrow ZZ^* \rightarrow 4l)}$$

- search for peak or excess in ZZ invariant mass distribution; ZZ peak or excess indicates V_D 

status

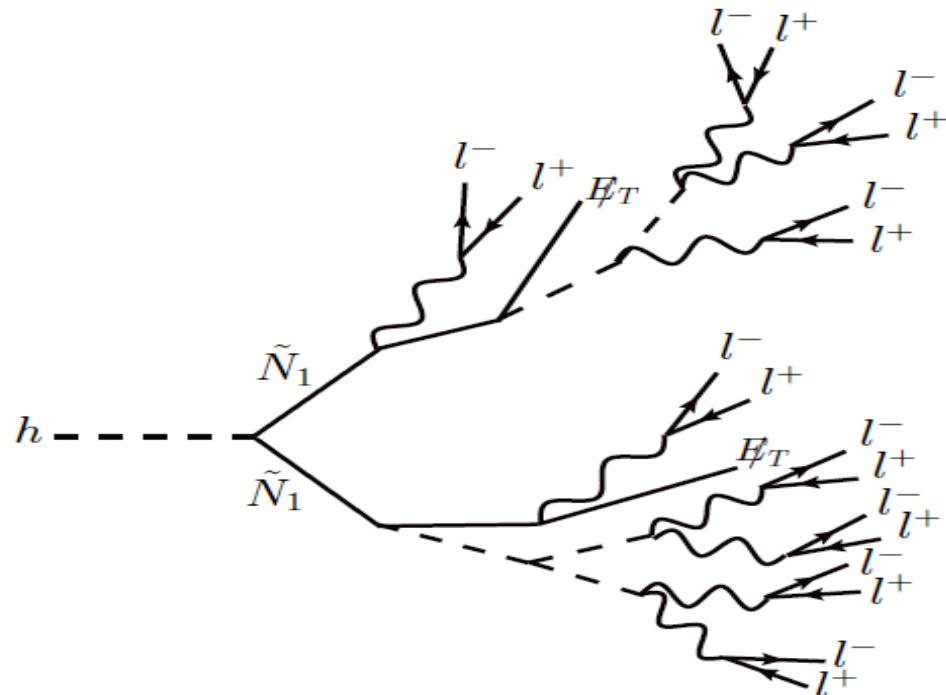
- statistical tools applied to subleading lepton pair distribution
 - Roostats
 - BumpHunter
- initial limit result (under review in ATLAS)
 - model independent analysis and result
 - will compare to model (as benchmark)
- extending studies to lower V_D masses
- will obviously benefit from increased statistics at high luminosities and energy



related studies I



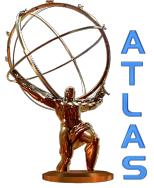
- lepton-jets Exotics WG (G. Watts and D. Ventura)
 - Higgs(125 GeV) decays to highly collimated leptons (low mass V_D)
 - [A. Falkowski, J. Ruderman, T. Volansky, J. Zupan PRL 105, 241801 \(2010\)](#)
 - The ATLAS collaboration hep-ex: arXiv:1212.5409v2



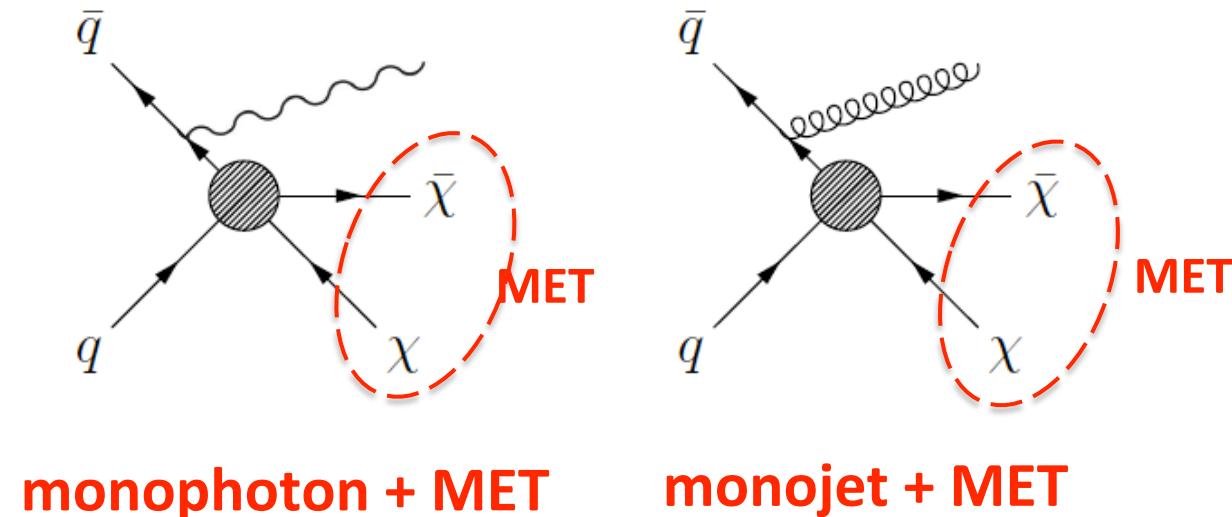
Higgs decays to leptons via neutralino in SUSY Hidden Valley model



related studies II



- lepton-jets Exotics WG (G. Watts and D. Ventura)
 - Higgs(125 GeV) decays to highly collimated leptons (low mass V_D)
 - invisible decays Higgs WG
- $q\bar{q} \rightarrow xH \rightarrow x + \text{invisible}$ $x = \gamma, \text{jet}$ for example
- mono-jet, mono-photon Higgs decays





related studies III



- lepton-jets Exotics WG (G. Watts and D. Ventura)
 - Higgs(125 GeV) decays to highly collimated leptons (low mass V_D)
- invisible decays Higgs WG
 - $q\bar{q} \rightarrow \gamma H \rightarrow \gamma + \text{invisible}$ for example
 - mono-jet, mono-photon Higgs decays
- heavy photon/A' searches at medium energy facilities
 - $e + p \rightarrow e' + p + A' \rightarrow e' + p + e^+ + e^-$ for example
 - Jlab, Mainz, DESY, ...
- Higgs decay to Z'Z' ($V_D V_D$) Higgs WG (K. Assamagan and M. Auroousseau)
 - S. Gopalakrishna, S. Jung, J.D. Wells **PRD 78 (5), 055002 (2008)**
 - JD Wells arXiv:0803.1243.2008